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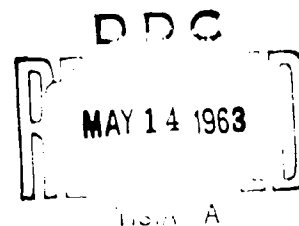
30 April 1963

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Flight Accessories Laboratory
Wright-Patterson AFB, Ohio

Project No. 0(3-3145) Task No. 61081

Prepared under Contract AF33 (616) -7230



ION PHYSICS CORPORATION
BURLINGTON MASSACHUSETTS

QUARTERLY TECHNICAL PROGRESS REPORT NO. 4

FEASIBILITY AND DESIGN STUDY FOR ELECTROSTATIC GENERATORS

30 April 1963

Flight Accessories Laboratory
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No. 0(3-3145)

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Project Manager - C. N. Coenraads

by

ION PHYSICS CORPORATION
Burlington Massachusetts

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- Ion Physics Corporation
Burlington, Massachusetts

30 April 1963

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1. INTRODUCTION

The technical data and findings derived during the period 16 January 1963 through 15 April 1963 are covered in this Progress Report.

Good progress has been made in the study of high voltage insulation in vacuum. The superiority of titanium alloy Ti-7Al-4Mo as an electrode material over other high strength materials, which was determined with small electrodes, has been confirmed for large area electrodes. So far, 45 kv/mm has been insulated over 1000 cm² areas with the titanium alloy and 35 kv/mm with stainless steel coated with an epoxy.

In the period under review, much time has been lost due to malfunctions of the high speed shaft seal on the 1 - 3 kw generator. Although a reasonable pressure level can be maintained with the shaft spinning ($< 10^{-5}$ torr), oil vapor, which is an acknowledged enemy of vacuum insulation, accumulates in the system to the detriment of the electric field properties of the generator. In spite of this, interesting data has been obtained on the operation of vacuum-insulated generators. Using a smaller machine, the first power run has been made using dielectric-coated stator blades and a rotor system completely at shaft potential.

2. VACUUM INSULATION STUDIES

2.1 NON-CONDUCTING COATINGS (20 CM² ELECTRODES)

2.1.1 Aluminum Oxide and Zirconium Silicate Coatings

Several tests were run using cathodes of 304 stainless steel which had been coated with either aluminum oxide or zirconium silicate by the plasma spray technique. The anodes used for these tests were fabricated from Ti-7Al-4Mo alloy and in all cases a nominal 1 mm gap was used. The surfaces of the cathodes as received were very rough, and some were polished to determine if this would have any effect on the results. The results are shown below:

<u>Coating</u>	<u>Insulation Strength</u>
Aluminum Oxide (polished)	30 kv
Aluminum Oxide (polished)	25 kv
Aluminum Oxide (unpolished)	40 kv
Zirconium Silicate (unpolished)	25 kv
Zirconium Silicate (unpolished)	30 kv

Failure occurred in all cases when pieces of the coating were caused to chip off during a discharge. These chips then entered the gap and, since they were charged negatively with respect to the anode, were accelerated across the gap by the field forces until they reached the anode. From this point on, the mechanism is subject to question and several could be postulated. However, the end result was the triggering of a new breakdown. This sequence caused continuous rapid breakdown

until either the power supply was overloaded or the gap became so badly contaminated with loose particles that only 2 or 3 kv could be supported without breakdown. Figure 1 shows the surface of one of these electrodes demonstrating the effects of this type of failure. The continued poor results obtained on all of the tests of electrodes coated in this manner are mainly due to the poor coating densities which can be obtained, and there will be no further testing of this type.

2.1.2 Nucerite Coated Cathodes^{*}

Sample electrodes with a Nucerite coating have been supplied by Pfaudler Permutit, Inc. and tested. The substrates were Inconel and the coating a glass bonded ceramic 0.030" thick. Several tests were run using these cathodes and anodes of 304 stainless steel. The results are shown in Fig. 2. These results indicate that this coating performs rather well in inhibiting breakdown. However, the process requires that a minimum of 0.020" of material be deposited to ensure against porosity, and it cannot be applied to curved surfaces with radii of less than 1" without the danger of its cracking and peeling off. Under these conditions, it seems rather impractical for application to generator blade surfaces. However, for application where small radius curvatures are not necessary, and especially where gaps are large and the coating thickness would be relatively small, this coating material is interesting.

2.1.3 Mylar Coated Cathode

A piece of mylar sheet 0.010" thick was epoxied to a 304 stainless steel electrode, and an experiment run using this piece as a cathode with an anode of Ti-7Al-4Mo alloy. The nominal gap was 1 mm. The insulation strength obtained was 40 kv. At 41 kv rapid breakdowns occurred at what

^{*} The voltages reached in obtaining these data were beyond the capacities of our systems and power supplies and were, therefore, tested in systems supported by AF08(635)-2166.



FIG. 1 PLASMA SPRAYED Al_2O_3 COATING AFTER TEST (MAG. $\times 7$)

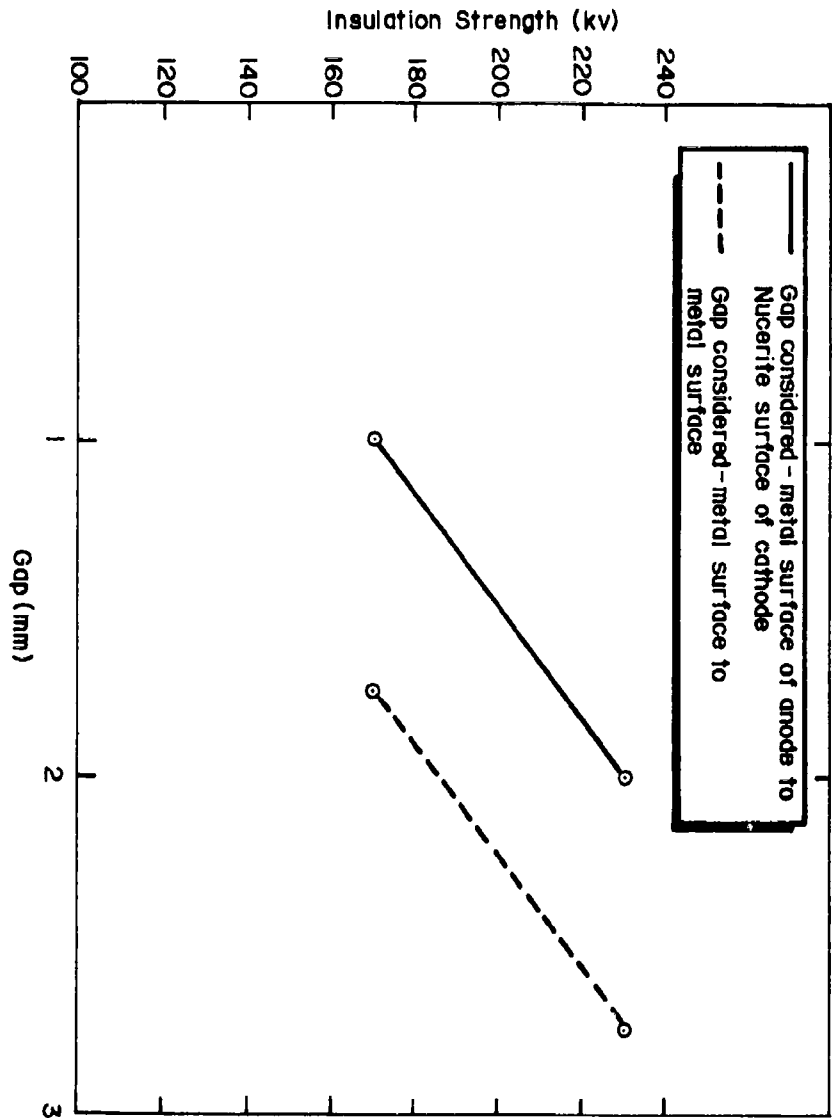


FIG. 2 PERFORMANCE OF NUCERITE COATING

appeared to be a single spot, after which the voltage was limited to 5 kv. Inspection of the electrodes after test showed that breakdowns had, indeed, taken place at one spot and that at this site the mylar was punctured and severely burned. In addition, the anode was coated with a heavy organic staining in an area of about 10 mm² opposite the failure site on the cathode. It should be noted that the epoxy bond was not a good one and that there were many air inclusions beneath the mylar. It is quite likely that ionization phenomena occurred in one of these voids causing the mylar, and subsequently the vacuum gap, to fail.

It is certain that techniques can be developed for bonding this mylar to the stainless steel without having gaseous voids, and further tests will be made. This method of coating appears attractive since mylar has a dielectric strength of 4 kv/mil. This means that, under optimum conditions of a faultless mylar piece, if a 40 kv breakdown should occur, a 10 mil thickness of mylar would be capable of withstanding the total voltage. The prospect of bonding a large piece of mylar to the stators of the generator to obtain a coating which would permit 40 kv to be withstood across the gaps without failure after a few of the almost inevitable conditioning sparks, appears, from a simplicity standpoint, to warrant further investigation. Test electrodes are now being prepared.

2.1.4 Epoxy Coatings

Three 304 stainless steel electrodes have been coated by a spray technique by Reed and Barton Company as mentioned in Quarterly Report No. 3. The results obtained from tests run using these as cathodes opposite anodes of Ti-7Al-4Mo alloy and with a gap of 1 mm are listed below:

<u>Coating</u> *	<u>Thickness</u>	<u>Insulation Strength</u>
Blue Epoxy	0.0008"	61 kv
Blue Epoxy	0.0006"	60 kv
Pink Epoxy	0.0008"	55 kv

*proprietary mixes

The most interesting aspects of these tests other than the high insulation strengths obtained relative to other coatings (see Quarterly Report No. 1), was that the number of breakdowns up to the points of maximum insulation strength was extremely low (5-20), and that current up to these points were less than 10^{-9} amperes. The results of these tests prompted the investigation of the blue epoxy on large area electrodes as will be mentioned later, and also on the stators of the small model generator as will be discussed elsewhere in this report.

A 304 stainless steel electrode was coated with epoxy by the fluidized bed method and tested opposite a Ti-7Al-4Mo anode, the vacuum gap being 1 mm. An insulation strength of 50 kv was obtained. At 55 kv rapid breakdown occurred and the power supply overloaded. An accumulation of particles could be seen in the gap and, therefore, the test was terminated. Inspection of the electrodes after test revealed that several large pieces had been chipped out of the coating. One of these was about 3 mm in diameter and was in the shape of a cone, the apex of which had originally been in contact with the substrate. The coating was 40 mils thick. This was necessary to guarantee against porosity. The coating was judged to be too brittle and required too thick a layer to be of practical use.

2.1.5 Anodized Ti-7Al-4Mo Cathodes

Three tests were run using cathodes of anodized Ti-7Al-4Mo alloy opposite non-anodized electrodes of the same alloy. The nominal gap in all tests was 1 mm. Two sets gave insulation strengths of 80 kv, one set of which had no breakdowns occur below 55 kv, and the second set none below 65 kv. The third set gave an insulation strength of 70 kv and had no breakdowns occur below 55 kv. The test results were somewhat clouded by the fact that the steatite standoffs which support the electrode fixture plates and insulate them electrically from each other began to experience failure by both surface flashover and volume puncture at the highest voltages. This is unusual since these same standoffs have withstood better than 100 kv without previous evidence of failure. They had been

in service for nearly a year and for about 500 hours by actual test time. New standoffs have been installed and the end conditions improved according to the results of a series of tests run on dielectric standoffs during this program and reported in Feasibility and Design Study for Electrostatic Generators, TR-61-105, Vol. II.

These results with anodized titanium cathodes are interesting with respect to the voltages reached before breakdown. The tests will be repeated under more favorable conditions (new standoffs) and, if the results are again encouraging, large area studies using anodized Ti-7Al-4Mo cathodes will be initiated.

2.2 EFFECT OF SURFACE FINISH

Three sets of Ti-7Al-4Mo electrodes have been prepared with varying degrees of surface finish to test the effect of this parameter on vacuum breakdown. The results are listed below along with those previously obtained with electrodes polished to the best finish possible with our equipment.

<u>Type of Finish</u>	<u>Insulation Strength</u>
600 grit silicon carbide	65 kv/mm
0.3 micron Al_2O_3	40 kv/mm
0.05 micron Al_2O_3 (with scratches)	100 kv/mm
0.05 micron Al_2O_3 (with no scratches)	100 kv/mm

This is further evidence that, up to a point, the obtainable insulation strength increases with surface smoothness. However, in polishing with 0.05 micron Al_2O_3 there seems to be nothing gained in removing each and every small scratch. This is very important since this phase of the polishing operation is extremely time consuming. These tests will be repeated to determine if the results are reproducible.

2.3 PRESSURE VARIATION STUDIES

Experiments at IPC in the very high voltage range ($\sim 10^6$ volts) under AF08(635)-2166 demonstrate that breakdown voltage for a given gap (~ 1 cm) can be much higher at 10^{-4} torr than at 10^{-6} torr. Consequently, tests have been conducted to determine the effects of increasing the pressure in the vacuum system on vacuum insulation strength at small gaps using small area (20 cm^2) electrodes. The pressure was varied in the region 3×10^{-7} torr to approximately 10^{-1} torr where the system was suddenly filled with a glow discharge, as would be expected from the Paschen Law characteristic (long path discharge). Several gases were used including O_2 , N_2 , H_2 , Ar, and the residual gases of the vacuum system when the pumps were turned off and the system allowed to outgas. There was no appreciable improvement observed with any of these gases either with respect to current decrease or breakdown frequency decrease except with the system residual gas. With this gas, the current decreased from 30 μ amperes to 10 μ amperes, at a pressure in the 10^{-3} torr range and voltage at 50 kv, but the breakdown frequency increased considerably.

2.4 LARGE AREA STUDIES

2.4.1 Ti-7Al-4Mo Electrodes

A test has been run using large area (1000 cm^2) electrodes with a vacuum gap of 1 mm. An insulation strength of 45 kv was obtained. A summary of the results obtained over a range of areas with both Ti-7Al-4Mo and 304 stainless steel is shown in Fig. 3. This is the first known data demonstrating area effect in vacuum breakdown, although much work of a similar nature has been done in association with other dielectric media.¹ The embryonic state of this study requires that more experimental work be done and that a thorough analysis be made to determine if there is a reasonable relationship between these results and those which would be predicted by extreme value theory.²

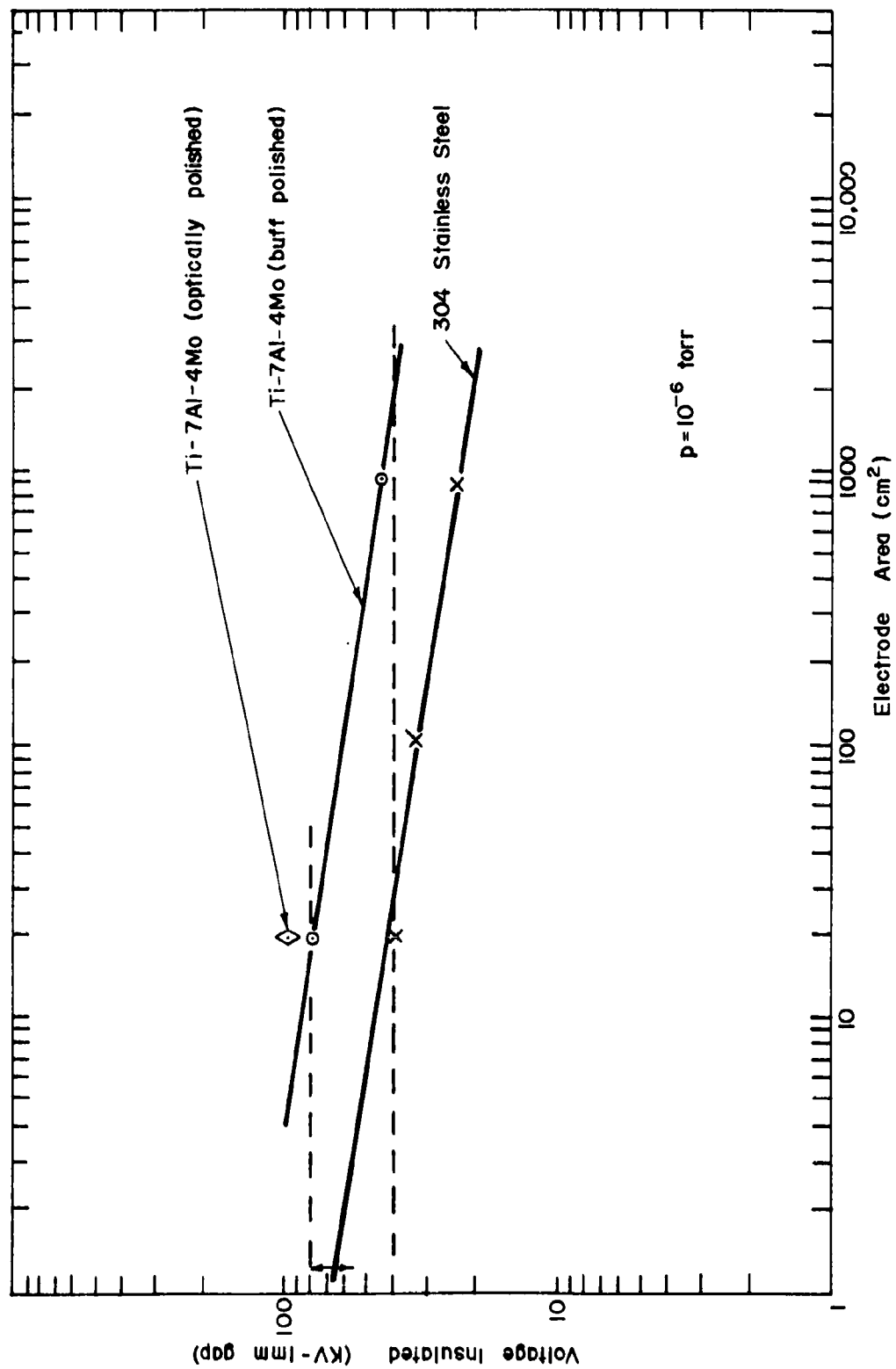


FIG. 3 ELECTRODE AREA EFFECT

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the present generator rotor (AM-355) with one fabricated from the titanium alloy. The result of this test was that with the Ti-7Al-4Mo electrode as a cathode, 25 kv was insulated across a 1 mm gap. The polarity was reversed and again 25 kv was insulated. However, this second test is, perhaps, inconclusive since it was conducted after the electrodes had experienced many discharges during the first test. Therefore, another test will be conducted with Ti-7Al-4Mo as the anode.

2.5 FUTURE

The following tests will be given prime consideration during the next quarter:

- 1) Anodized aluminum cathodes with both AM-355 and Ti-7Al-4Mo anodes. The aluminum cathodes will be prepared by first depositing a pure aluminum layer in vacuum and then anodizing this layer. This will be done for one, two and three layer surfaces. The first tests will be conducted using 20 cm² electrodes with an eye toward applying the process to large area tests.
- 2) Large area anodized 60-61 aluminum alloy with both 304 stainless steel and Ti-7Al-4Mo anodes. These tests will determine the feasibility of replacing the present generator stators with anodized aluminum alloy and whether or not this is practical without replacing the rotor with Ti-7Al-4Mo. In addition, it will be the first step in approaching the ultimate goal of 80 kv/mm over large areas.

- 3) Large area studies with Reed and Barton epoxy coated 304 stainless steel cathodes opposite both 304 stainless steel and Ti-7Al-4Mo anodes. These tests should determine the steps necessary to obtain;
 - a) 40 kv/mm for 1 kw output on the present generator, and,
 - b) 63 kv/mm for 3 kw output on the present generator.
- 4) Large area Ti-7Al-4Mo opposite 304 stainless steel. These tests will determine the feasibility of replacing the present rotor with one of Ti-7Al-4Mo without changing the stators.

3. 1 KW GENERATOR

The mechanical tests on the shaft-seal assembly mentioned in the previous quarterly report, No. 3, (p. 21) were continued with good results. No excessive vibration occurred during testing. The seal labyrinth temperature was measured and found to be below -40°C at all times during operation. Bearing temperatures did not rise above 60°C . The assembly was tested at top speed (11,400 rpm) for 10 minutes and no deterioration in mechanical performance was observed. The vacuum level in the main chamber was held at 2×10^{-6} torr. At this time no oil leakage could be detected.

A series of electrical tests was then made to determine the ultimate insulation strength of the generator gap after the latest improvements. In the first test the generator gap was set at a nominal gap of 0.060"; the minimum occurring gap was 0.052". The capacitance values were;

$$C_o = 500 \text{ } \mu\mu\text{f}, \quad C_m = 1000 \text{ } \mu\mu\text{f}, \quad C_s = 160 \text{ } \mu\mu\text{f}$$

where C_o is minimum capacitance, C_m is maximum capacitance, and C_s is the parasitic capacitance to ground. If these values are placed in the expression for power, the resulting equation is

$$P = 3.59 \times 10^{-9} n V_d^2$$

where n is the speed in rpm and V_d is the voltage across the generator gaps. At 10,000 rpm and 40 kv, the values of n and V_d for which the machine was designed, the power output would be 575 watts.

The conditioning process was then started using the circuit given in Fig. 4.

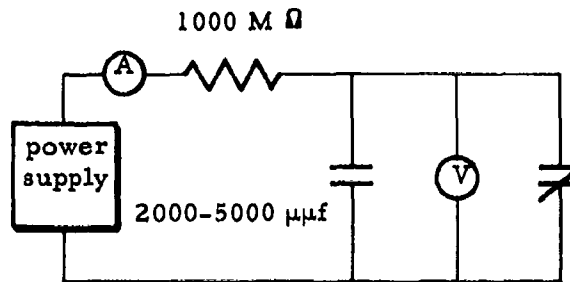


Fig. 4 - Conditioning Circuit

The parallel capacitor of 5000 uuf was added to increase the discharge energy and reduce the voltage fluctuations caused by the periodic capacitance variation. The series resistor established a large recharging time constant. This was desirable to avoid an avalanche of discharges which could be triggered by a single discharge.

The conditioning process was slow thus presenting an opportunity for more careful observation than in previous tests. The pressure throughout the tests was 1.2×10^{-6} torr, the speed 4,000 rpm and the current level always below 10 μa . The insulation performance is presented in a tabular form on the following page.

Running Time hrs.	Insulation Level kv	Number of B. D.
1.25 (+ 1.25)	16	(+ 24) 24
2.10 (+ .85)	20	(+ 36) 60
3.75 (+ 1.65)	24	(+ 70) 130
5.50 (+ 1.75)	28	(+ 92) 222
8.15 (+ 2.65)	30	(+110) 332

The efforts to reach a higher insulation level were extended for three more hours but without result. An insulation of 30 kv without breakdowns was possible for periods as long as 20 min. The total running time at this point was 11.10 hours.

It is known that at very high voltages (large gaps), higher fields can, in some instances, be supported at pressures approaching 10^{-4} torr than at 10^{-6} torr. Consequently, an attempt was then made to improve the insulation level by operation at a higher pressure ($\sim 6 \times 10^{-5}$ torr, nitrogen). After 4.5 hours neither improvement nor decrease in insulation level was noted and it was concluded that there is no significant pressure effect with the generator configuration.

The total running time at this point was 15.6 hours. No deconditioning occurred during shutdowns (short or overnight). However, after a 2-day interval in the 10^{-6} torr range without testing, deconditioning took place. Contamination, too, was increasing as was indicated by the colored deposit on the liquid nitrogen cooled cold finger in the vacuum system. After

an attempt to recondition the generator had proved a tedious process (up to 20 kv in 2 hours), it was decided to glow discharge clean the generator system with argon. A glow discharge was maintained for 20 minutes at a pressure of 7×10^{-2} torr and with a discharge current of 150 ma at 240 V. Afterwards the generator was conditioned to 30 kv in twenty minutes. Moreover, conditioning beyond this point appeared possible and an insulation level of 32 kv was obtained in one hour and could be steadily maintained for 10 minutes. The highest short duration insulation level was 34 kv. Total running time at this point: 19.6 hours.

Three interesting observations can be made from the results of the above tests, one of which is illustrated by curve A in Fig. 5. As expected, the number of discharges needed to raise the insulation level by a given amount increases with the insulation level. The curve shows a sharp increase in the number of breakdowns needed to raise the insulation level above 30 kv, indicating that the ultimate plateau was closely approached in the generator test run.

A second observation was the importance of the discharge energy. The capacitance in parallel with the generator was kept at 5000 μmf up to 25 kv. It was observed that around this voltage level occasional heavy discharges would trigger a number of low voltage discharges whereafter the gap would rapidly condition to the previous level. By decreasing the parallel capacitance, this phenomenon did not occur. It was found that when the discharge energy $\left(\frac{1}{2} CV^2\right)$ exceeded approximately 1 joule, a reduction in this energy was needed for further conditioning.

A third phenomenon was observed when the speed was varied from 4000-3000 rpm and from 4000-6000 rpm. In both cases deconditioning occurred initially but only in the latter case could the voltage level be restored after some reconditioning sparks. Apparently the combination of electrostatic loading and centrifugal stiffening causes this effect. By decreasing the speed

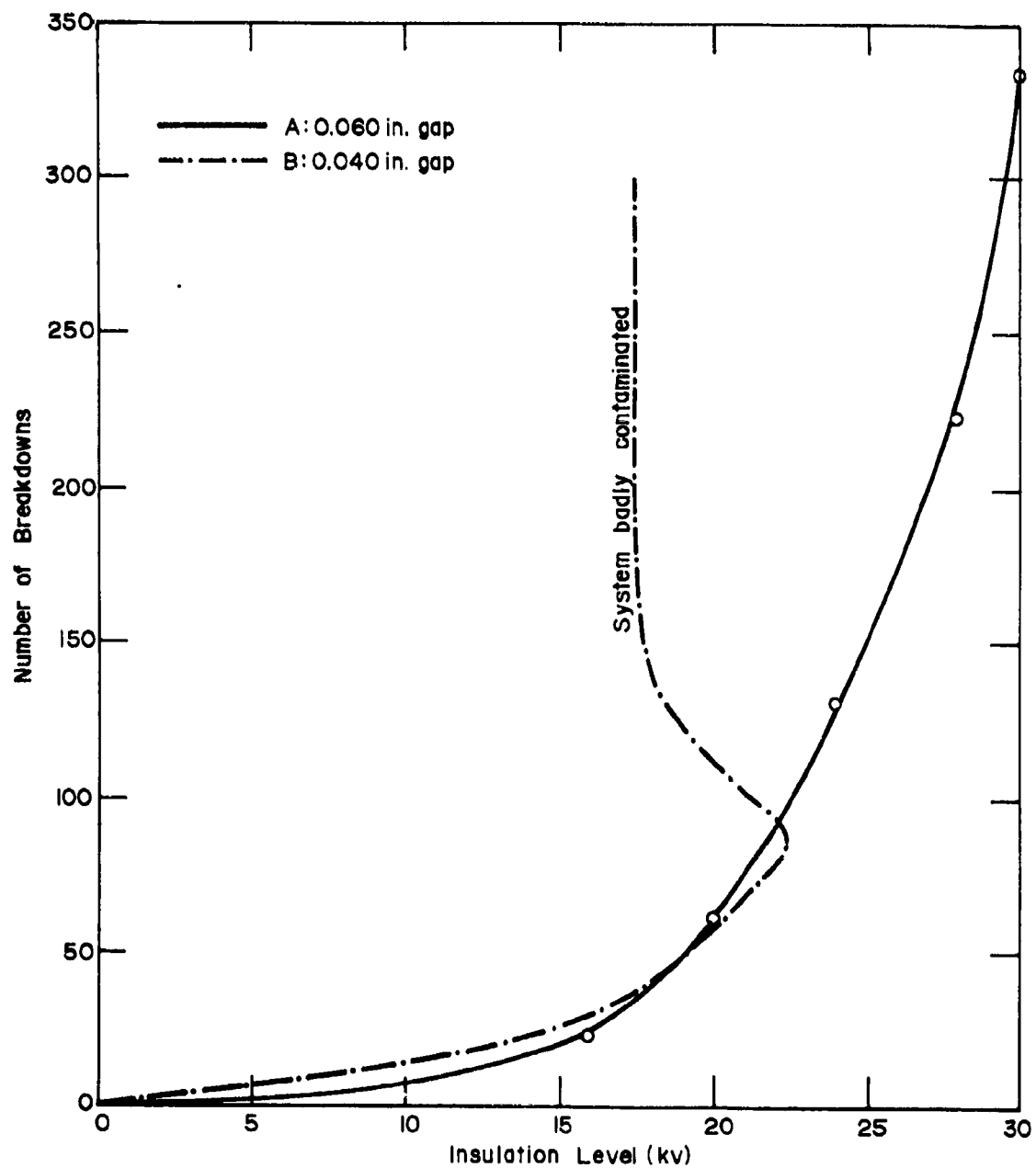


FIG. 5 INFLUENCE OF VOLTAGE LEVEL ON CONDITIONING SPARKING RATE

it is possible that the smallest gap will become even smaller at a deflected blade because of the decrease in centrifugal stiffening, thereby causing the voltage insulation level to fall slightly. On the other hand, an increase in speed will tend to straighten a deflected blade, thereby decreasing an originally large gap which must then be conditioned to the previously obtained voltage level.

Upon inspection after this run of almost 20 hours, it was found that the seal had leaked a considerable amount of oil vapor, most of which was frozen on the labyrinth. Heavy organic staining existed at the discharge areas on the blades. One blade, in particular, was heavily marked by discharges. This blade had earlier been found to have a relatively bad deflection and had been bent back. The blades were then inspected and it was found that several blades, including the heavily marked blade, were deflected beyond the tolerance limits (0.004"). The tolerances were improved by pressing these blades back. An experiment was made to ascertain that no single blade was weaker than the others under axial loading. No discrepancies were found.

After the necessary cleaning a second effort was made at the same gap setting to condition the generator to the highest possible value. This test was aimed primarily at determining the reproducibility of the previous results. Moreover, a very high emission current level ($\sim 2 \times 10^{-4}$ a) indicated the presence of organic contamination. Glow discharge cleaning in argon did not improve the situation. The maximum voltage obtained was 31 kv but unstable and at a current level of 200 μ a. It should be noted that the vacuum in the main generator chamber was fluctuating around 4×10^{-6} probably indicating that the shaft seal was admitting bursts of gas or vapor. The cold finger in the vacuum chamber, moreover, was seen to be highly contaminated.

Upon inspection inside the system after the test, it was found that contamination was heavy. Accentuated stains on every second rotor blade indicated that contamination had already occurred during standstill through the pumping slots in the stators. The deposit on the cold finger was mostly oil, but a little mercury was also present. This mercury comes from the mercury diffusion pumps which were chosen originally instead of oil diffusion pumps to limit organic contamination in the system. Mercury pumps are very intolerant of organic contamination, and it seems likely that the presence of oil from the seal in the pumps influenced their back-streaming properties. Seal leakage was definitely at a higher level than desirable and it was determined to polish and clean the seal, then reassemble the generator with a 1 mm (0.040") gap.

After the generator was assembled with a nominal gap of 0.040" and a minimum gap of 0.035", the capacitance values were:

$$C_o = 630 \mu\mu f \quad C_m = 1530 \mu\mu f \quad C_s = 160 \mu\mu f$$

If n and V_d are again assumed to be 10,000 rpm and 40 kv respectively, as on page 15, the output power under the above conditions would be 1280 watts. Before electric field conditioning tests could be started, a leak developed in the face seal which limited the ultimate vacuum obtainable in the main chamber to above 1×10^{-5} torr. In addition, the mercury diffusion pumps were not operating properly. The seal was removed and disassembled, and the mating ring reground and polished. Meanwhile, the mercury diffusion pumps were disassembled and found to be badly contaminated with oil. It is certain that this heavy contamination was seriously affecting the operation of the diffusion pumps, especially the 2" pump which evacuates the seal chamber. After repairs had been made, the system was again prepared for test.

Field conditioning tests were performed using the technique described previously. However, the best ultimate vacuum obtainable in the secondary chamber was 5×10^{-3} torr at 5000 rpm. The gaps conditioned rapidly up to 22.5 kv (Fig. 5, curve B). At this point, however, heavy breakdowns began to occur and the gap deconditioned down to 17 kv maximum insulation strength. At the same time, the liquid nitrogen cold finger in the test chamber became heavily coated. The tests were stopped and the chamber opened for inspection. The cold finger was covered with a mixture of oil and mercury. The mercury was found to have come from the 2" pumping system which was again heavily contaminated with oil. By comparing plot B with A in Fig. 5, it would appear that but for the onset of severe contaminations, the generator would have conditioned up to about 30 kv.

At this point a new face seal was fitted and the mating ring relapped to within two helium light bands using the techniques developed for electrode polishing. This is considerably better than the manufacturer's specifications. Also, the 2" mercury pump on the seal chamber was replaced by a 2" self-fractionating oil diffusion pump which should handle the oil from the seal more readily. In addition, an annealed copper ring was silver soldered to the cover of the secondary chamber in such a way that it pressed firmly against the knife edge of the rotating portion of the labyrinth assembly. The system was then reassembled and the shaft turned slowly until the knife edge had worn a groove into the copper ring. With the system under vacuum, the speed was gradually increased to 4000 rpm. This knife edge-copper seal gave a very low conductance from the secondary to the primary chamber. The system was run for a total of four hours, during which time the speed was at 4000 rpm for thirty minutes. At this speed the pressure in the secondary chamber was 6.7×10^{-5} torr, and in the primary chamber 9.8×10^{-7} torr. Most important, however, was the fact that no contamination could be found on the liquid nitrogen cold finger. Hopefully, this will reduce the amount of oil contamination and the limitations it imposes on voltage insulation.

The difficulties described above are typical of the troubles caused by the high speed shaft seal. It is specified contractually that generator high speed shaft sealing be accomplished with "state of the art" techniques, but since there were none at the commencement of the program the present seal concept had to be developed, which, in itself, has advanced the state of the art. This was done with minimum possible effort following the intent of agreement with ASD. There is still no substitute for our seal, nor, to our knowledge, is one forthcoming in the near future. This limitation has cost, and is costing, the e. s. g. program a great deal of time. It was always known that some organic contamination would leak through the dynamic face, but it was felt that the freon-cooled labyrinth ($< - 30^{\circ}\text{F}$) would trap this. This is obviously not so, probably because the leakage occurs in bursts, and flow through the labyrinth is viscous rather than molecular.

In the meantime, it had been decided to coat, with epoxy, the stators of the model generator which has been described, with its performance, in reference 3. The epoxy which was applied was the Reed and Barton coating discussed in Sections 2.1.4 and 2.4.2. It was expected to obtain information which could be applied later to the 1 - 3 kw model.

In the first test the stators were coated with a single R & B epoxy coating. The nominal gap in this machine was set at 0.060", but the tolerances are poor since the machine was intended originally as a large-gap machine and the minimum gap was 0.038". When tested, an insulation level of 38 kv was obtained with a minimum gap of 0.038" after a short conditioning period. No appreciable current was flowing ($\sim 10 \mu\text{a}$). At 38.4 kv the coating punctured. The generator was next coated with a double coating of R & B epoxy. An insulation strength of 29 kv was easily obtained. At this point, one of the lucite stand-offs began to flash over. It was decided to make a power run before disassembly to repair this fault, and 60 watts were generated before a bearing failure forced a shutdown. The necessary repairs are being made to continue this test. This was the first power run made using dielectric-coated blades and a rotor system at shaft potential (no rotating ceramics or need for special commutation).

4. CONCLUDING REMARKS AND PROJECTED EFFORT

The limitations which are placed on generator testing because of shaft seal problems have already been discussed. If the backup "wear in" copper seal approach is not satisfactory, it appears that there is little further that can be done within the present state of the art, and without a specific seal development program. The present seal arrangement on the 1-3 kw generator is an integral part of the rotor system, and it is unlikely that a new concept could be applied without much redesign.

From the above information on the electric fields which can be supported, it is obvious that irrespective of coatings there would be considerable advantage to making the generator with a titanium blade system if the seal contamination problem can be solved. The initial large area study (yet to be confirmed) with buff-polished titanium indicated an attainable field strength of 45 kv/mm. The superiority of titanium alloy Ti-7Al-4Mo over the other metals which have been tested using large area electrodes is demonstrated in Fig. 6. By extrapolation of existing data on generator power, such a field strength with the present generator geometry would produce about 1.7 kw at 11,500 rpm (the top speed of the drive system). However, higher powers may be achievable with coated titanium.

Vacuum insulation experiments to date indicate that to gain the advantage of the better material, both anode and cathode should be made of titanium alloy. It was hoped previously that a significant improvement in generator performance could be made by substituting a titanium rotor and retaining the AM355 stators. The decision on proceeding with the expense of substituting titanium alloy rotor and stators will be made through consultation with the Flight Accessories Laboratory.

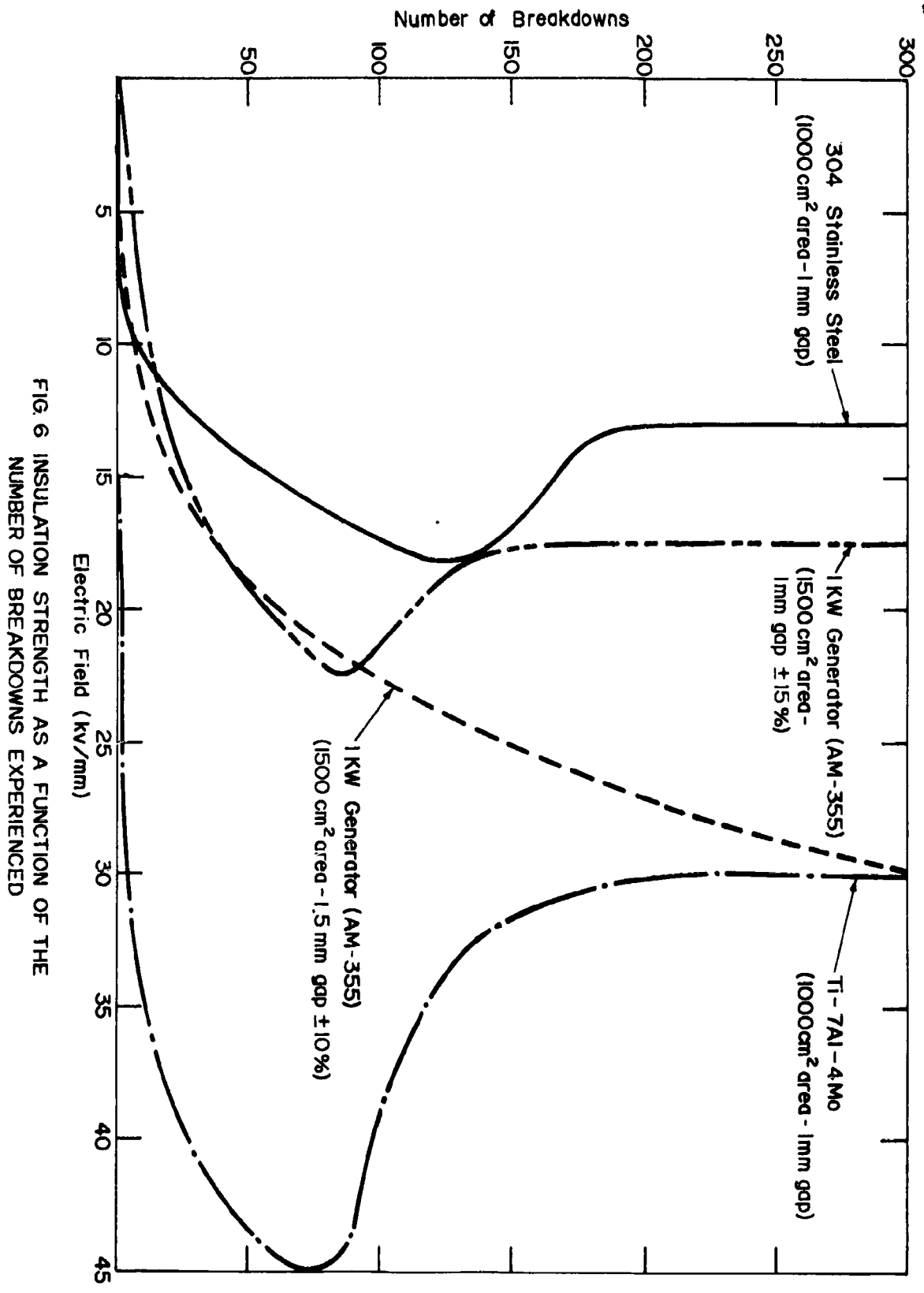


FIG. 6 INSULATION STRENGTH AS A FUNCTION OF THE NUMBER OF BREAKDOWNS EXPERIENCED

With the fields so far obtained using coatings which could be applied to the present machine stator blades, at least 40 kv/mm should be possible (~ 1.3 kw). The development of techniques for applying high temperature (e. g. glassy) coatings to the present generator will not be attempted within the present program. Effort will, however, continue in the investigation of coatings which can be applied to the present machine blades pursuant to the attainment of a 3 kw machine.

The major effort on vacuum insulation during the next quarter has been indicated in Section 2. 5.

5. REFERENCES

1. Hill, L. R. and Schmidt, P. L., "Insulation Breakdown as a Function of Area," AIEE Trans. 67, p 442, 1948.
2. Gumbel, E. J., "Statistical Theory of Extreme Values and Some Practical Applications," National Bureau of Standards-Applied Mathematics Series No. 33, Washington, Government Printing Office, 1954.
3. Denholm, A. S., Trump, J. G., and Gale, A. J. "High Voltage Generation in Space: The Parametric Electrostatic Machine," Progress in Astronautics and Rocketry, 3: "Energy Conversion for Space Power," Academic Press, p 745, 1961.